Bio-Inspired Sensing and Behavior for Planetary Surface Exploration

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Outline

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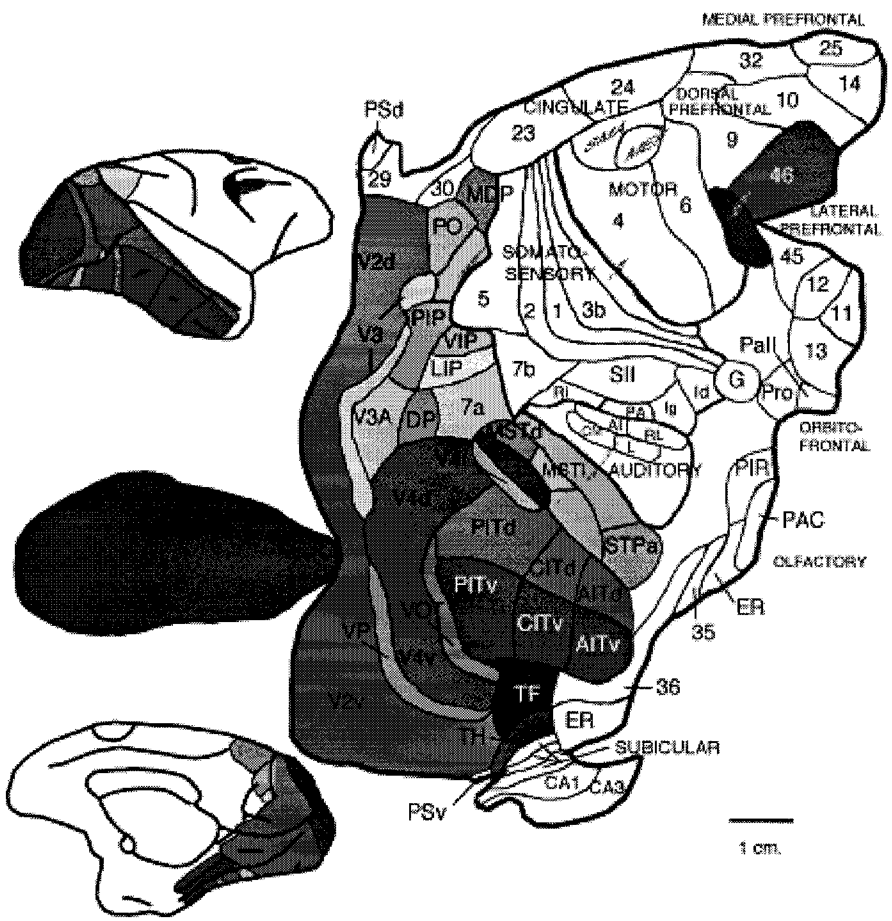
Introduction

- Robotic missions beyond 2019 will probably be robotic presursors to a Mars manned habitat deployment.
- Such missions will require robust sensing and control systems for long duration activities
- Single rover missions will evolve into deployment of colonies of multiple, heterogeneous cooperating robots.

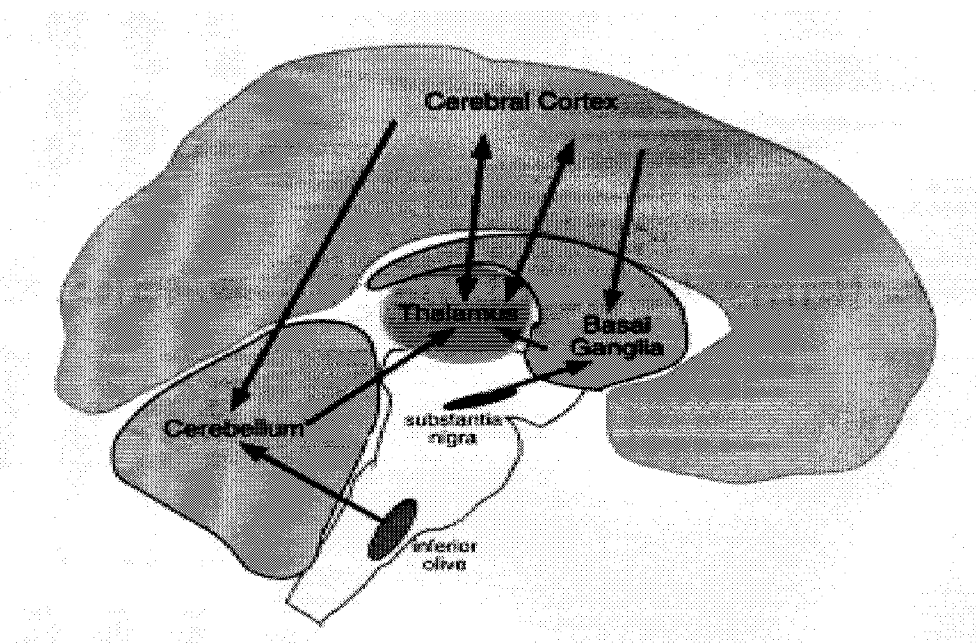
Human Visual Cortex



Visual Pathways

- Visual cortex viewed as four pathways
  - Motion: MCL of retina & LGN to orientation+direction-selective cells in layer 4B of area V1 and through thick stripes of area V2 into area V5
  - Dynamic form: MCL of retina & LGN to orientation-selective cells in layer 4B of area V1 and through thick stripes of area V2 into area V3
  - Color: PCL of retina & LGN into area V4 from blobs in layers 2 & 3 of area V1 through thin stripes of area V2
  - Form linked to color: PCL of retina & LGN into area V4 from interblobs in layers 2 & 3 of area V1 through interstripes of area V2

Biological Action Selection



•Basal ganglia and cerebellar cortex work by selectively pausing the tonic inhibition they normally exert on sites capable of activating sensory-motor pathways through frontal cortex.

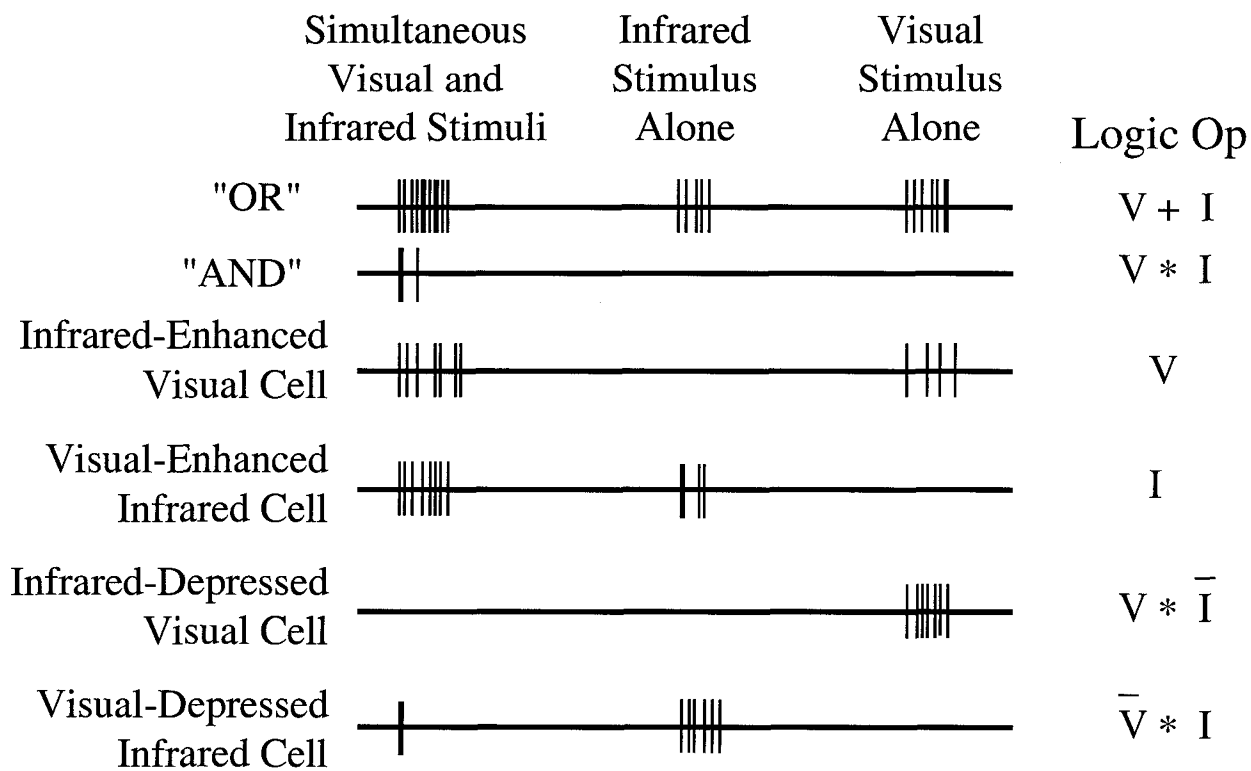
•Basal ganglia complex (BGC) uses perceptual analyses provided by the cerebral cortex to decide which sites to disinhibit in the optic tectum (OT; homologous to the superior colliculus in mammals) which controls orienting and other actions in amphibians and terrestrial vertebrates.

Biological Investigations

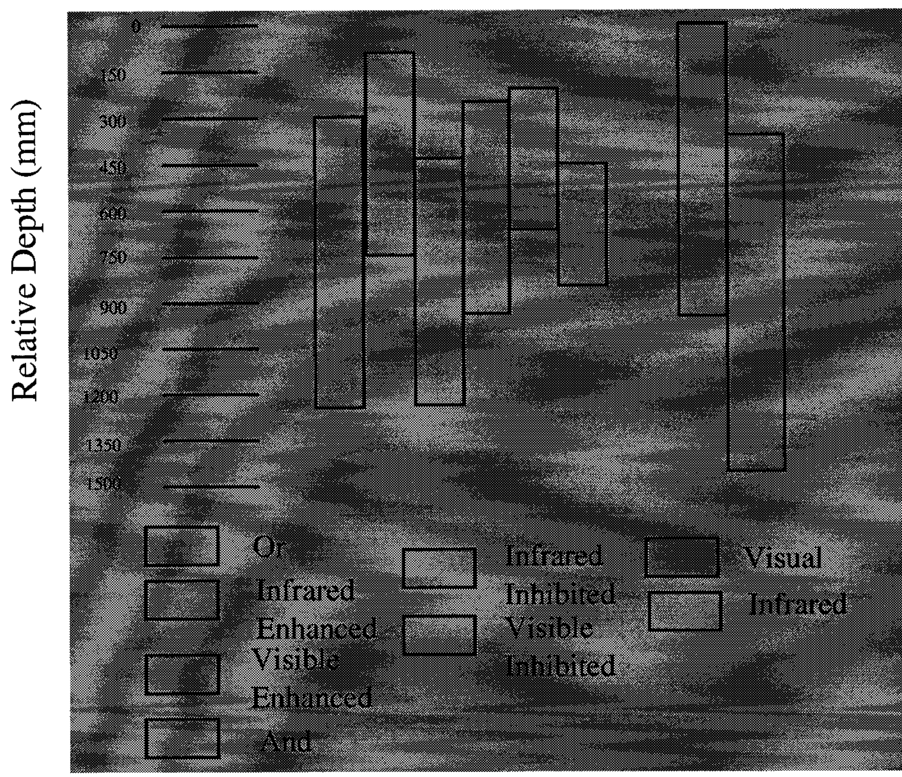
- Bullock & Diecke (1956) - extensive study of single neuron thermal properties
- Hartline, Kass & Loop (1978) - optic tectum mapping and existence of AND/OR bimodal neurons
- Newman & Hartline (1981) - existence of six types of bimodal neurons
- Terashima & Liang (1991) - thermal neuron properties in the LTTD

Bimodal Responses

Inputs		Bimodal Neuron					
Vis	IR	OR	AND	IRENH	VISENH	IRINH	VISINH
0	0	0.1	0.0	0.1	0.1	0.1	0.1
0	1	0.75	0.1	0.1	0.5	0.1	0.9
1	0	0.75	0.1	0.5	0.1	0.9	0.1
1	1	0.9	0.75	0.9	0.9	0.1	0.2

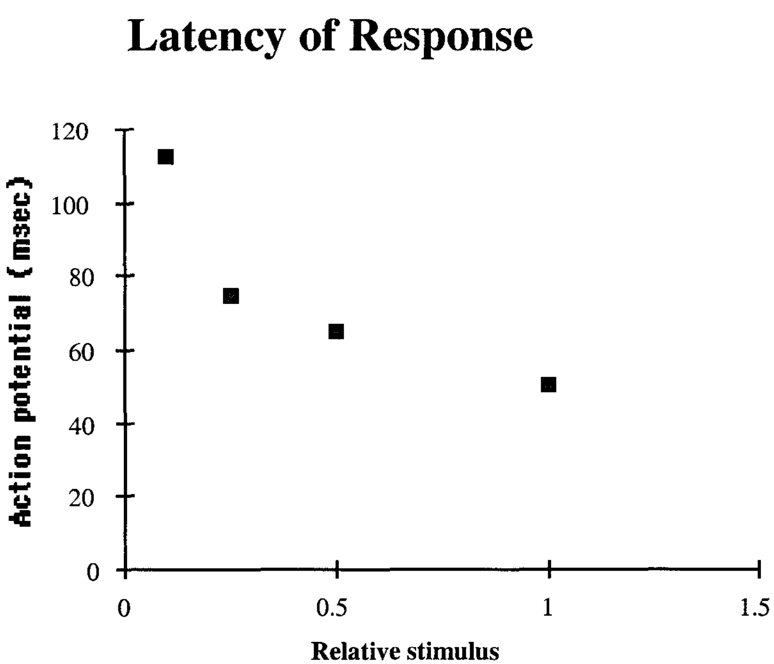


Organization of Neurons



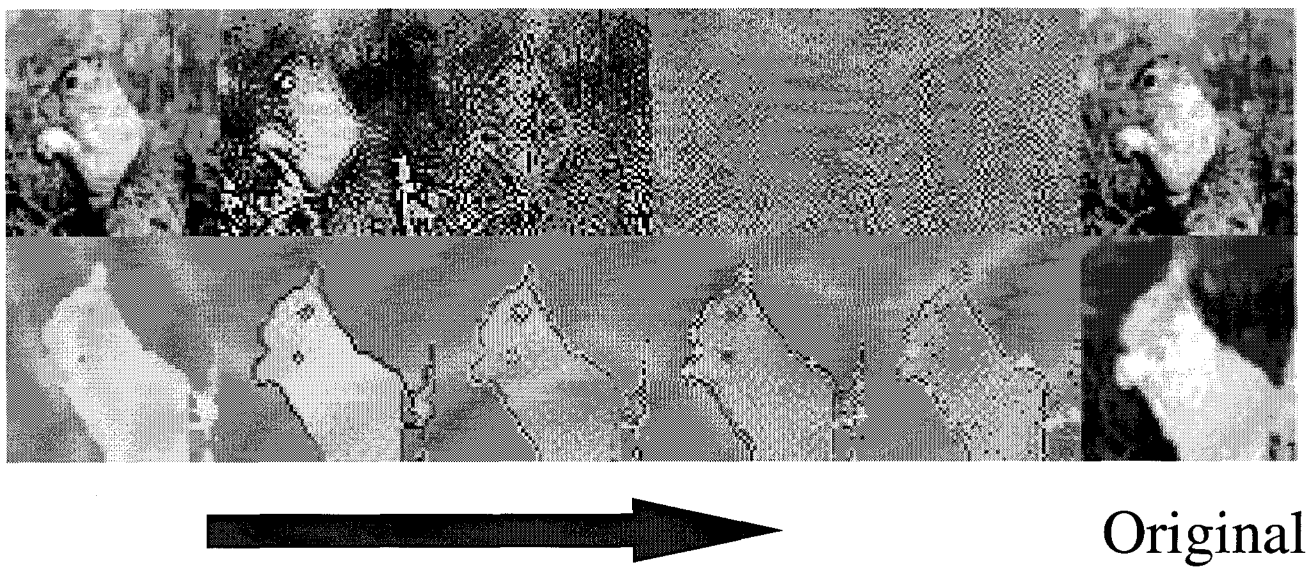
- Zone from 450 to 650 mm contains all 8 types of neurons
- Interactions between different neuronal types leads to broader set of logic operations (ex. XOR)
- Interactions between networks of different neuronal types leads to set of image analysis operations

Motion Sensitivity



- Thermal neurons exhibit nonlinear latency effects
- Stimulus with strong contrast to background causes rapid firing of neurons
- Highly non-linear decrease in firing frequency as contrast decreases
- Similar behavior seen in primate visual responses

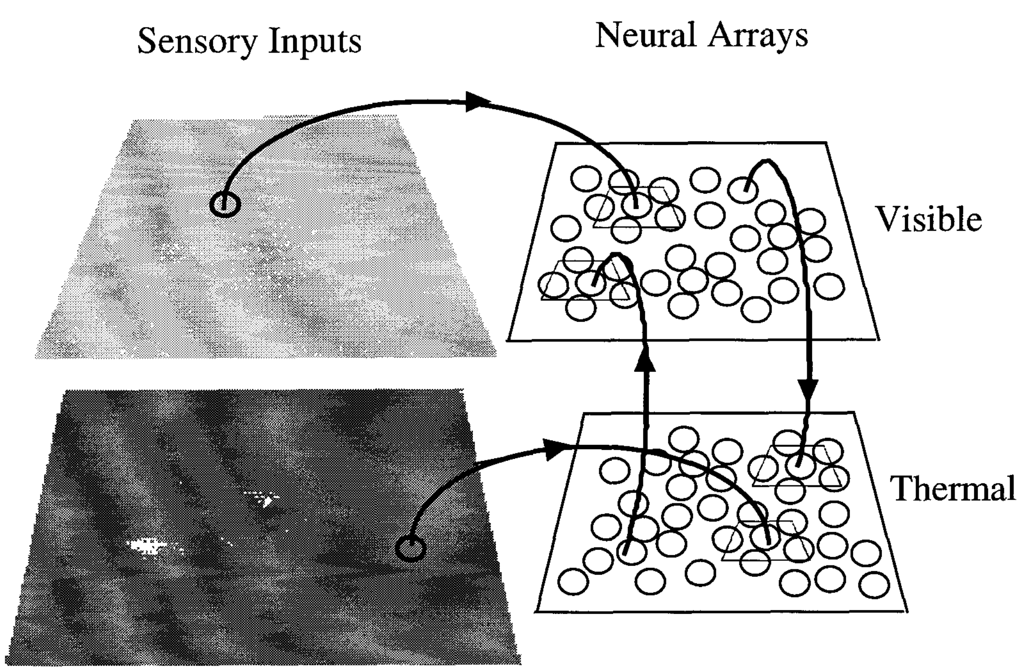
Independent Arrays



• Visible array quickly accommodates

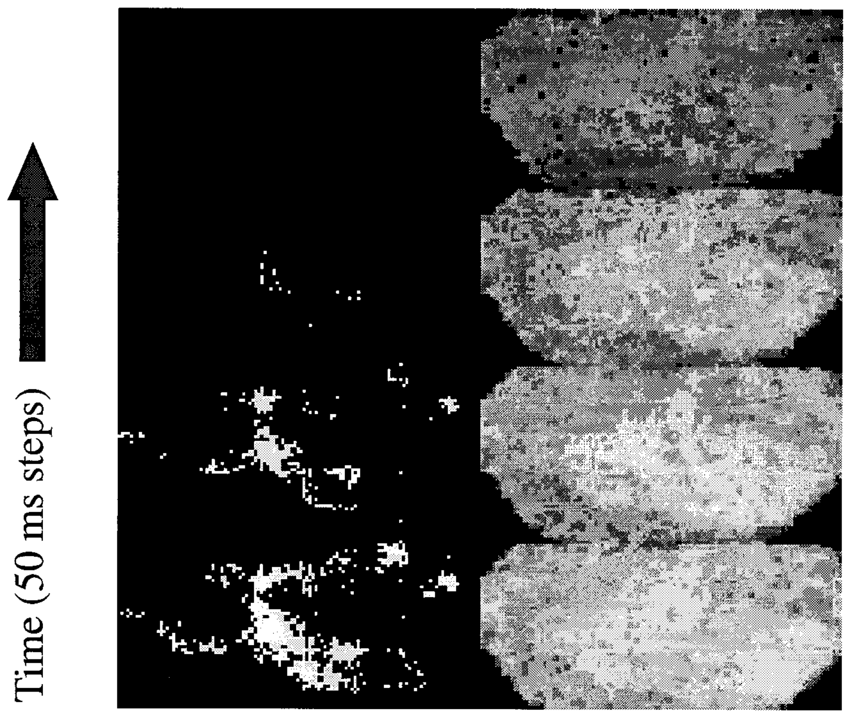
• Thermal array enhances edges due to latency characteristics

Network Interactions



- Probabilistic feed from sensors to arrays with neighborhood at reception point
- Fibers between arrays can be excitatory or inhibitory
- Spatial registration between arrays and resolution of sensors controls specific result

Interacting Unimodal Neurons



Visual array - no thermal interactions

Visual array with thermal enhancement

- Sensor array without interactions quickly accommodates and stops firing
- Excitatory interaction between arrays slows accommodation and enhances full field
- Type of dynamic multimodal gain control

Bimodal Temporal Analysis

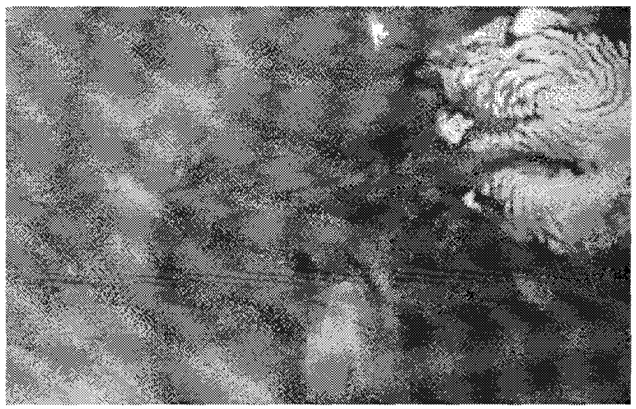


Image_1 : 4/30/1999

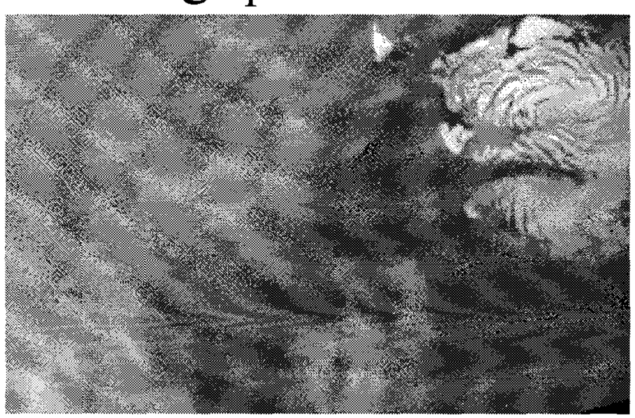


Image_2 : 5/01/1999

Clouds in North Polar Region of Mars

$\text{Image}_1 * \overline{\text{Image}_2}$

Dominant cloud patterns delineated despite background variations

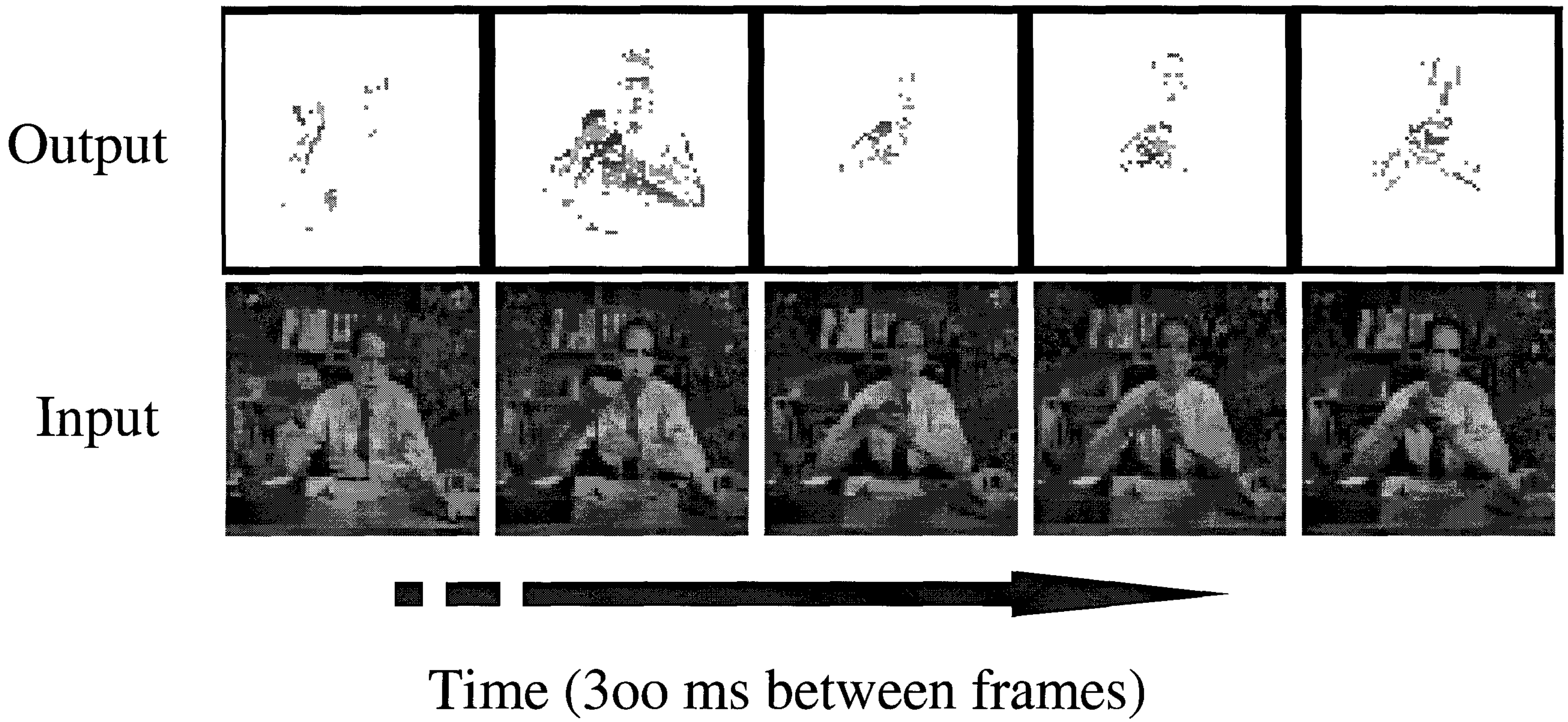
Array Processing

QuickTime™ and a
None decompressor
are needed to see this picture.

Salesman Sequence

- Primary motion is with right arm holding box
- Noise in image frames hampers straight frame difference analysis
- Textured background leads to occlusion/disocclusion problems for motion analysis

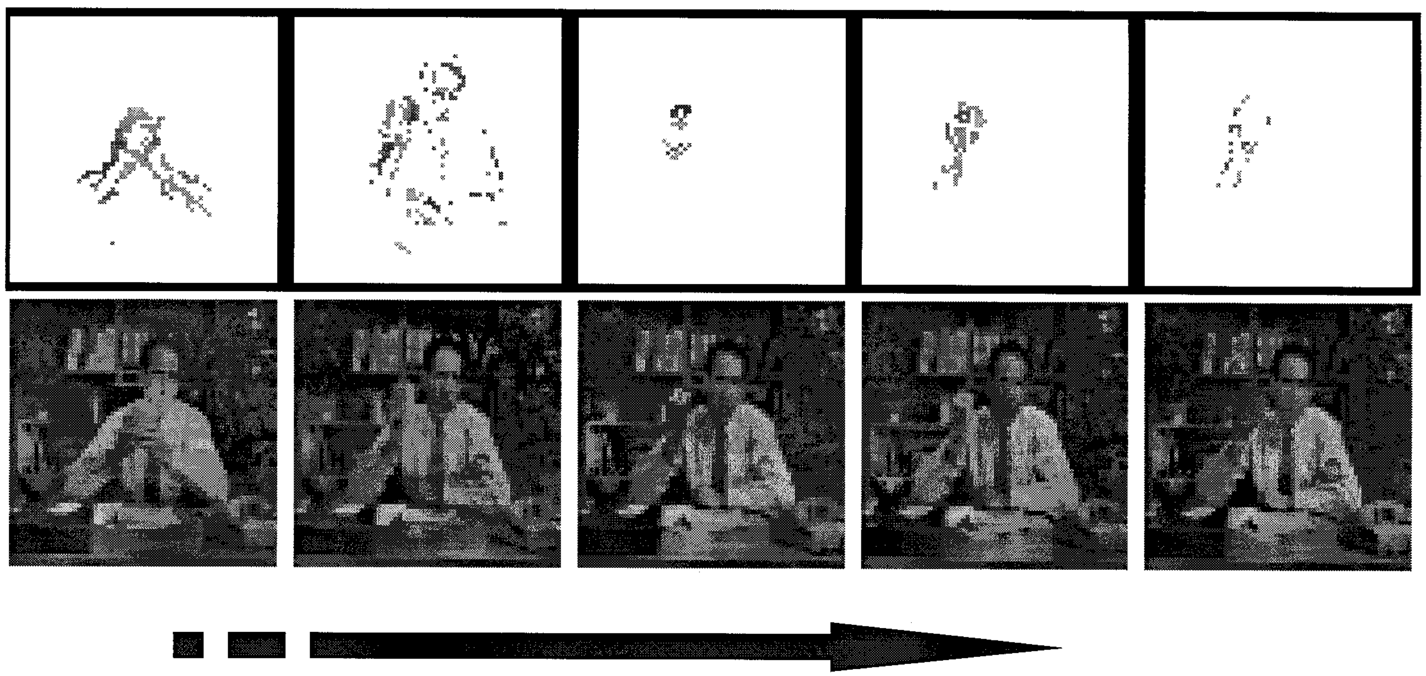
Array Output



Array Output (con't)

Output

Input

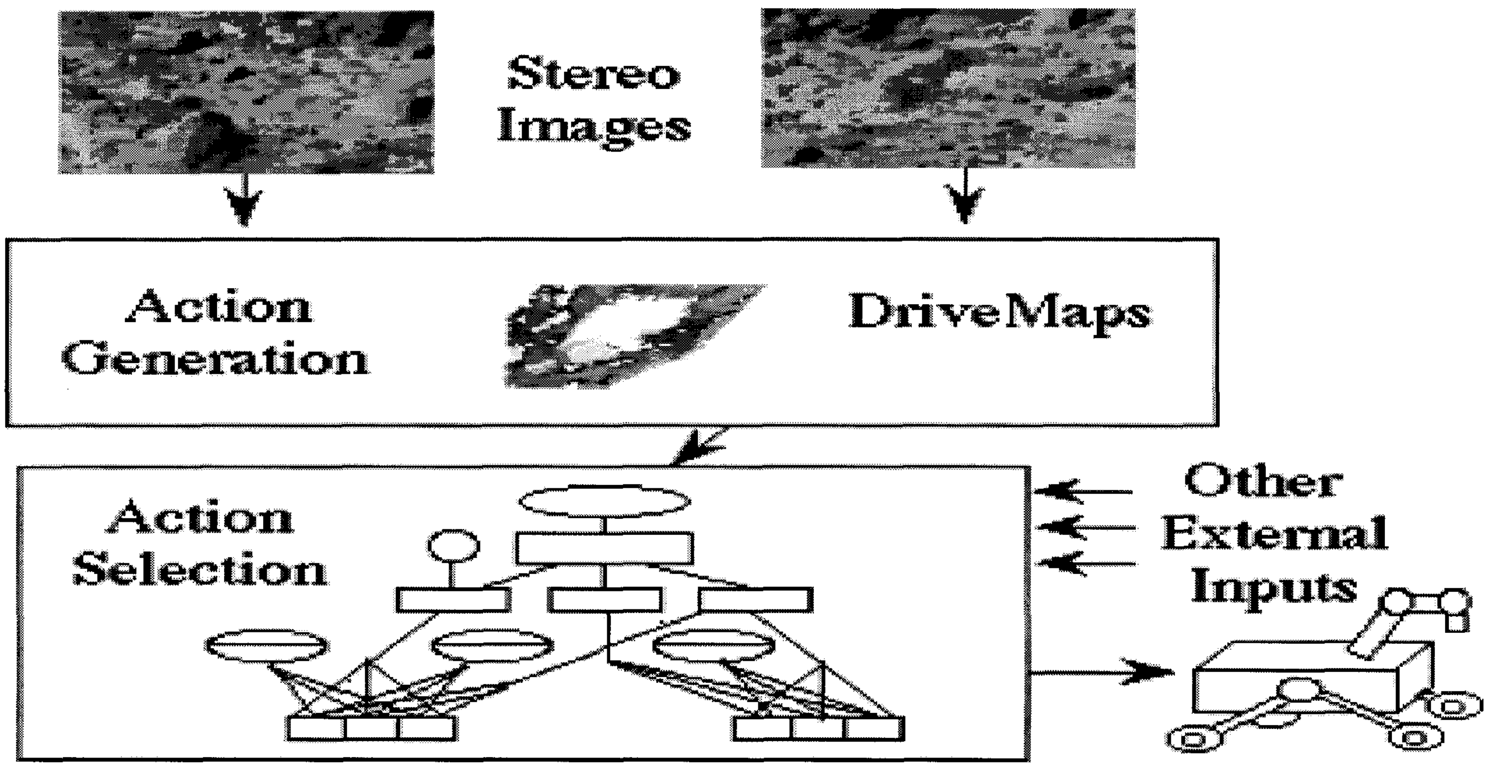


Time (3oo ms between frames)

Behavior Generation

Biologically Inspired System for Map-based Autonomous Rover Control (BISMARC)

BISMARC Organization



Map Making

- Evidence for *place* cells in hippocampus for mapping environmental information using spatially non-contiguous populations
- Right hippocampus involved in route following in collaboration with landmark coding in left lateral prefrontal cortex [Maguire, et al 1997]
- Framework captured in BISMARC using landmark encoding coupled with actions leading to landmark

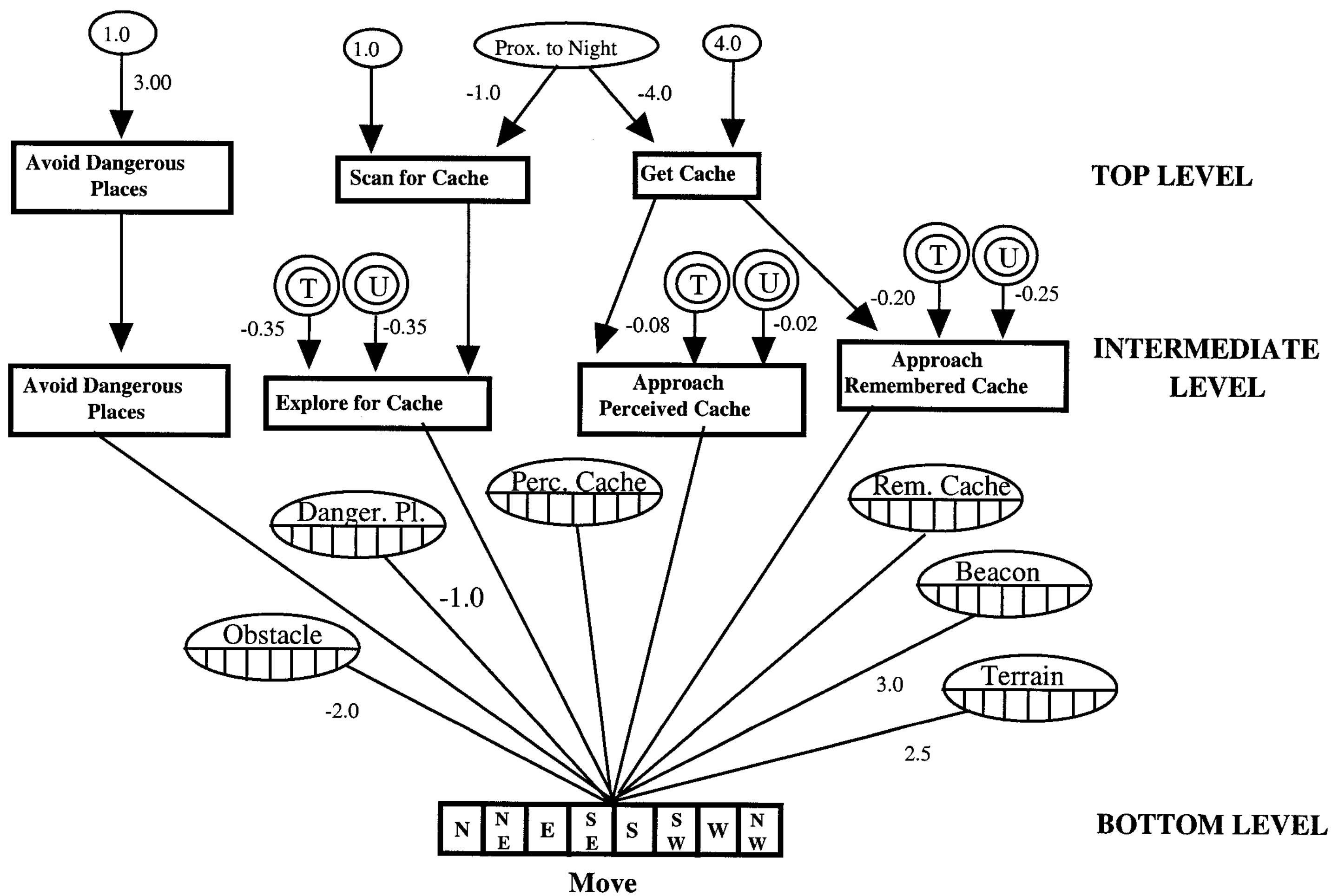
Memory Mechanism

- BISMARC has map-based memory similar to hippocampus
- Landmarks corresponding to obstacles and goals extensively mapped
- LTM stores landmarks for comparison to perceived inputs
- Probabilistic update of memories using perceived inputs

Desired Capabilities for Action Selection

- Low computational requirements
- Reactive even in uncertain environments
- No loss of internal state information
- Capable of combining conflicting behaviors
- Sensory input localized to decision modules where used

Move Subsystem



Activation Strength

$$A_S = P_d * (1.0 - \text{dist}) * (1.0 - P_u)$$

P_d is the normalized sensor input for sensor S

P_u is the perception uncertainty

dist is the normalized distance to a perceived object - combination of stereo and LTM traces

Experimental Setup

- Random starting positions and cache placement
- Timestep of 0.1s
- 10% loss of traction in rocky terrain
- 1km X 1km study area with 5 cm resolution
- Top speed of 15 cm/sec
- Cache acquisition time of 1 hour prior to return to lander

Experimental Setup (con't)

- Single scout rover
  - Color stereo cameras
  - 3 DOF manipulator
  - 1 week battery lifetime
- Two retrieval rovers
  - Grayscale stereo cameras
  - 5 DOF manipulator
  - 2 week battery lifetime

Summary of Experimental Results

- 2000 simulated missions with success defined as all four cache containers retrieved
- 98.9% mission success with no component failures
- 12% success rate with component failures and no fault tolerance
- 46% success rate with component failures and fault tolerance

Summary

- Rich set of computational operations can be realized with unimodal and bimodal neuron models
- Independent and interconnected networks of these neurons provide image analysis capabilities
- Developed fault tolerant autonomous control system for multiple planetary rovers
- 98.9% success rate in 2000 simulated multi-rover missions

Current Directions

- Replacement of heuristic action selection with basal ganglia models [with Steve Grossberg, BU]
- Comparison of system to theoretical Multiple Objective Behavior Control [Pirjanian (2000)]
- Integration of sensor fusion into action selection mechanism
- Port of system to SRR